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(54) **Method and apparatus for measuring distances using an acoustic signal**

(57) An acoustic distance measuring device comprising, a transmitter 2, for propagating an acoustic wave towards a target, 13, a first receiver, 4, located a known reference distance, AB, from the transmitter and between the transmitter and the target for sensing the propagated acoustic wave, a second receiver, 5, located a fixed distance from the first receiver between the first receiver and the target for detecting the acoustic wave echo signal from the target, and a timer for measuring the time of flight of the acoustic wave from the transmitter to each of the receivers; the target distance, AD, is calculated from the known distances between the transmitter and the receivers, and the time of flight of the acoustic wave to each of the receivers.

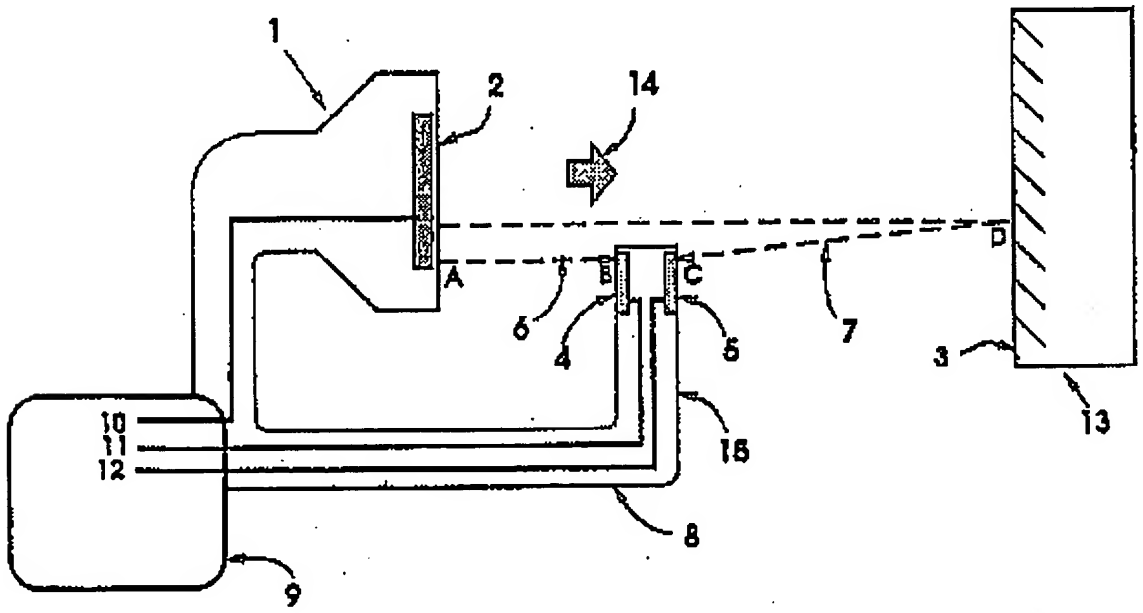

Figure 1

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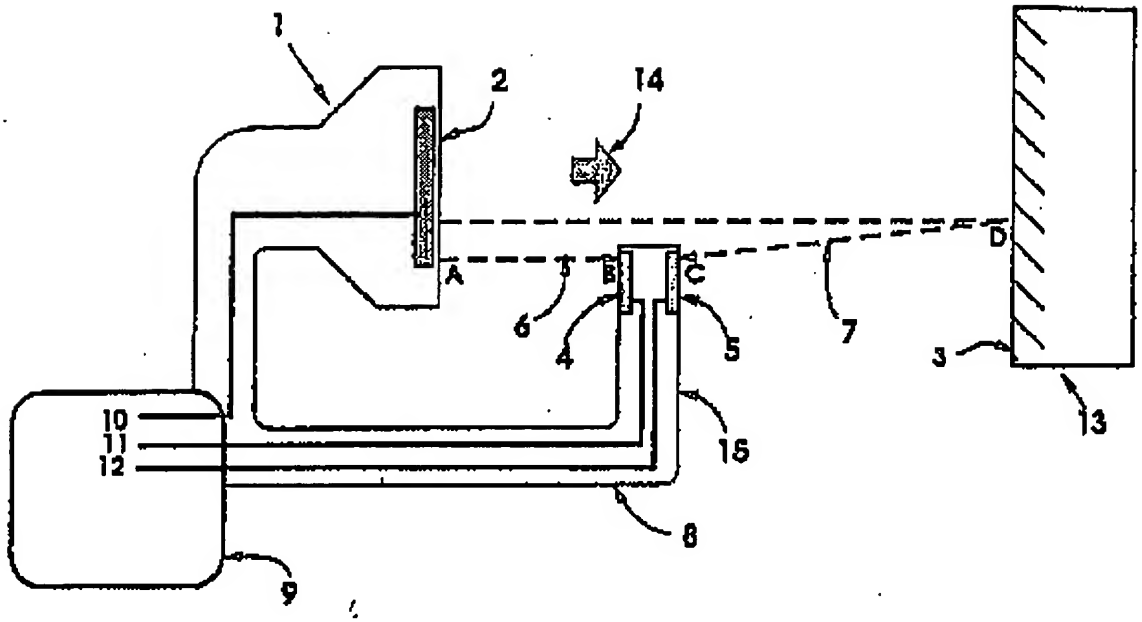

Figure 1

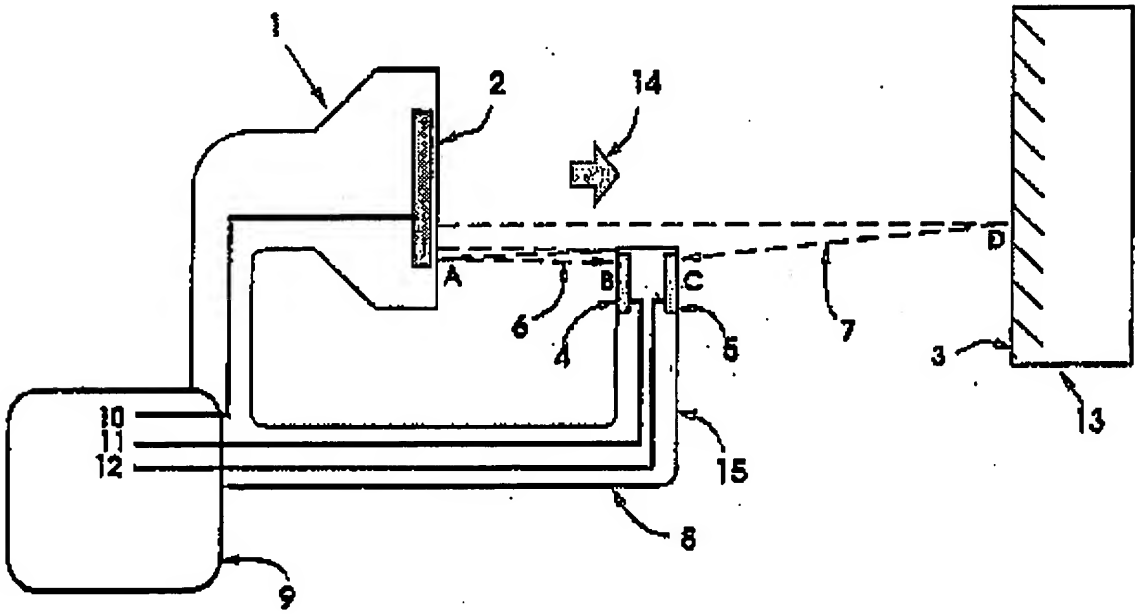

Figure 2

METHOD AND APPARATUS FOR MEASURING DISTANCES USING AN ACOUSTIC SIGNAL

This invention relates to method and apparatus for measuring distances using an acoustic signal. In particular it is concerned with the measurement of distance by measuring the time of flight of an acoustic signal from an acoustic generator to a target and back, as an echo, to a receiver. The target can be any surface capable of reflecting the signal and can be formed by a liquid or solid. A purpose of the method and the apparatus is to provide for determining changes in the distance of the target surface relative to the receiver.

Distance measuring instruments exist in which an acoustic signal is generated by an active member acting as an acoustic wave transmitter and an echo of that signal is detected by the same active member acting as a receiver. Such instruments commonly make use of a transmitter/receiver active member embodied in a piezo-electric ceramic component. The time between the electrical excitation of the active member and its electrical response to the resultant echo from the target is a measure of the distance of the target from the instrument given the speed of the acoustic signal through the medium through which it is propagated. The medium is commonly air in which the speed of sound has a known relationship to the temperature of the air. It is necessary to know the temperature of the air so that the speed of sound can be accurately calculated. The temperature used must be representative of the average temperature of the air through which the sound is passing. As there is often a temperature gradient between the instrument and its target the temperature of the air in the immediate vicinity of the sensor will not usually be representative of the average temperature and so not conducive to the making of accurate measurement.

According to a first aspect of the present invention there is provided a method of measuring the distance of a target surface on a path from an acoustic transmitter/receiver to a target surface comprising the steps of:

1 propagating an acoustic signal along the path from the transmitter/receiver to the target surface and to a first receiver; the first receiver being located in the

path at a reference-distance from the transmitter/receiver and intermediate the transmitter/receiver and the target;

2 starting a timer simultaneously with the propagating step;

3 detecting the arrival of the propagated signal at the first receiver;

4 measuring as a reference-time the time taken for the propagated signal to arrive at the first receiver from the transmitter/receiver ;

5 detecting the arrival of an echo of the acoustic signal reflected from the target surface at a second receiver located in the path intermediate the target and the transmitter receiver; the first and second receivers being spaced along the path by a separation-distance;

6 measuring as a target-time the time taken for the arrival of the echo of the signal at the second receiver;

7 determining the distance between the transmitter/receiver and the target by computing as a ratio the reference-time with the difference between the target-time and reference-time to determine a distance representing twice the distance between the second receiver and the target, by applying this ratio to the reference-distance and then subtracting the separation-distance.

According to a second aspect of the present invention there is provided a method of measuring the distance of a target surface from an acoustic receiver along a path comprising the steps of:

1 causing an acoustic signal generator to propagate an acoustic signal towards the target surface along the path;

2 detecting the passage of that acoustic signal at a first point on the path at a fixed distance from the generator and between the generator and the target surface;

3 starting a timer simultaneously with signal detection step;

4 directing a first part of the acoustic signal from the first point towards a reflector at a fixed reference-distance from the first point;

5 detecting the return of an echo to the first point from the reflector of the first part of the acoustic signal;

6 recording as reference-time the time taken for the passage of the first part of the acoustic signal to the reflector and back to the first point;

7 detecting the arrival of an echo of the acoustic signal from the target surface at a second point at a fixed separation-distance from the first point and between the first point and the target surface;

8 recording as target-time the time taken for the arrival of the echo of the signal at the second point;

9 determining the distance between the second-point and the target by multiplying the ratio of the reference-time to the target-time by the reference-distance and then subtracting one half of the separation-distance.

According to a first preferred version of the first or second aspect of the present invention wherein the separation-distance is zero.

According to a third aspect of the present invention there is provided apparatus for measuring the distance to a target surface characterised by:

1 a transmitter for propagating an acoustic signal along a path towards the target;

2 a platform located at a fixed position along the propagation path and partially intercepting the acoustic signal;

3 a first acoustic receiver positioned on the platform to detect the propagated acoustic signal;

4 a second acoustic receiver positioned on the platform to detect an echo of the propagated acoustic signal from the target;

5 means for the control of the transmitter;

6 timing means for determining a time of passage of the propagated signal to the first acoustic receiver and a time of arrival of an echo from the target at the second acoustic receiver;

7 computation means for deriving the distance of the target relative to the apparatus from the determined times and the known positions of the receivers relative to the transmitter.

According to a fourth aspect of the present invention there is provided apparatus for measuring the distance to a target surface comprising:

1 a transmitter for propagating an acoustic signal along a path towards the

target, the transmitter further being capable of reflecting acoustic signals received along the path back along the path of propagation;

2 a platform located at a fixed position along the propagation path and partially intercepting the acoustic signal, the platform being shaped to reflect a portion of the propagated signal back towards the transmitter;

3 a first acoustic receiver positioned on the platform to detect the propagated acoustic signal and to detect a subsequent echo of that signal from the portion reflected along the path from the transmitter;

4 a second acoustic receiver positioned on the platform to detect an echo of the propagated acoustic signal from the target;

5 means for the controlling the transmitter;

6 timing means for determining a time of passage of the portion of the propagated signal reflected back to the transmitter and returned as a reference echo to the first acoustic receiver and the time of arrival of the echo at the second acoustic receiver from the target;

7 computation means for deriving the distance of the target relative to the apparatus from the determined times and the known positions of the receivers relative to the transmitter.

Typically in a preferred version of the third or fourth aspects of the present invention the separation distance is zero.

Amongst other advantages the present invention provides an alternative to calculating the speed of sound from the air temperature in the vicinity of the transmitter. It achieves this by locating a reference target at a fixed and known distance from the transmitter (which distance is less than the distance of the target surface from the transmitter) and measuring the time of flight of the acoustic signal to the reference target and comparing that time with that of the time of flight to the target surface. In this way the effect of temperature gradient on the speed of sound between the instrument and the reference target are effectively backed off. Given the distance between the transmitter and the reference target is known and the times of flight of the acoustic signal are measured by the instrument then the distance to the target is readily computed. The closer the reference target is to the target surface, the more

accurate the measurement. The distance (D_t) of the target surface from the transmitter is then derived from the relationship:

$$D_t = L_r * T_t/T_r$$

(where: L_r is the distance between transmitter and the reference target;
T_t is the time of flight between transmitter and the target surface; and
T_r is the time of flight between transmitter and the reference target.)

The present invention makes use of a reference target which incorporates two receiver surfaces, one facing the acoustic transmitter and the other facing in the opposite direction towards the target surface. Both receiver surfaces are sensitive only to acoustic signals received towards and normal to their surfaces.

The advantage of this disposition of transmitter and receiver elements and the incorporation of receiver elements into the reference target is that the target surface can be allowed to approach close to the reference target so improving the ability of the system to resolve small changes of position of the target surface.

Embodiments of the invention will now be described with reference to the accompanying drawings of an apparatus for measuring distance of which:

Figure 1 is a schematic diagram showing the unit in use according to one operating mode; and

Figure 2 shows the apparatus of Figure 1 operating according to a second operating mode.

As both figures show virtually identical apparatus, though used in slightly different ways, the same references are used in both.

Figure 1

An acoustic transmitter 2, with active member 2A for generating an acoustic signal, is contained within a housing 1. An extension 8 projects form the housing and supports a platform 15 at a fixed distance AB from the transmitter 2. The direction of propagation of the acoustic signal from the transmitter 2 is on axis of propagation P in the outgoing direction of arrow 14. Target surface 3 serves to reflect an acoustic

signal arriving from the transmitter 2 along the propagation axis P. The face 3 is at a distance AD from the transmitter.

The platform 15 has two acoustic receivers 4, 5. Receiver 4 is aligned to receive signals in the direction of arrow 14. Receiver 5 is disposed to receive signals reflected from the target surface 3. In this case the receivers 4, 5 are spaced apart by a distance BC along the axis of propagation P between transmitter 2 and target 13. In an alternative embodiment a platform corresponding to platform 15 is shaped so that the two receivers 4, 5 are in the same plane along the axis of propagation (that is to say distance BC is zero).

A controller 9 serves to initiate a signal at the transmitter 2 through line 10 and to measure, relative to that initial signal, the time of arrival:

of the signal at receiver 4 by way of path 6; and

of the signal at receiver 5 by way of path 7;

through the lines 11 and 12 respectively.

To measure the distance AD, the controller 9 causes the transmitter 2 to emit an acoustic signal in direction 14 and at the same time, starts an internal timer (not shown). On arrival at the receiver 4, having traversed the known distance AB, the controller 9 detects the signal through line 11 and records the time, T_1, of the internal timer. On arrival of the echo of the transmitted acoustic signal from the target surface 3 at receiver 5 by way of path 7 having traversed the unknown path length ADC, the controller 9 detects the signal through line 12 and records the time, T_2, of the internal timer. AD is determined from the expression: $AB*(T_2/T_1 - 1)/2 - BC/2$

Figure 2

The transmitter 1 and the platform 15 are aligned so as to cause a portion of the propagated signal to reverberate between the platform 15 and transmitter 2.

In this case to measure the distance AD, the controller 9 provides for the transmitter 2 to emit an acoustic signal in direction 14. On arrival at the receiver 4, having

traversed the known distance AB, the controller 9 detects the signal through line 11 and starts an internal timer (not shown). This part of the signal follows the path 6 back to the member 2A whereupon it returns and returns to the receiver 4 where it is detected for a second time on line 11. At this instant, the controller 9 records the time, T_1, of the internal timer. On arrival of the echo of the transmitted acoustic signal from the target surface 3 at receiver 5 by way of path 7 having traversed the unknown path length ADC, the controller 9 detects the signal through line 12 and records the time, T_2, of the internal timer.

AD is determined from the expression: $AB(T_2/T_1) - BC/2$

CLAIMS

1 A method of measuring the distance of a target surface on a path extending from an acoustic transmitter/receiver to the target surface comprising the steps of:

1 propagating an acoustic signal along the path from the transmitter/receiver to the target surface and to a first receiver; the first receiver being located in the path at a reference-distance from the transmitter/receiver and intermediate the transmitter/receiver and the target;

2 starting a timer simultaneously with the propagating step;

3 detecting the arrival of the propagated signal at the first receiver;

4 measuring as a reference-time the time taken for the propagated signal to arrive at the first receiver from the transmitter/receiver ;

5 detecting the arrival of an echo of the acoustic signal reflected from the target surface at a second receiver located in the path intermediate the target and the transmitter receiver; the first and second receivers being spaced along the path by a separation-distance;

6 measuring as a target-time the time taken for the arrival of the echo of the signal at the second receiver;

7 determining the distance between the transmitter/receiver and the target by computing as a ratio the reference-time with the difference between the target-time and reference-time to determine a distance representing twice the distance between the second receiver and the target, by applying this ratio to the reference-distance and then subtracting the separation-distance.

2 A method of measuring the distance of a target surface from an acoustic receiver along a path comprising the steps of:

1 causing an acoustic signal generator to propagate an acoustic signal towards the target surface along the path;

2 detecting the passage of that acoustic signal at a first point on the path at a fixed distance from the generator and between the generator and

the target surface;

3 starting a timer simultaneously with signal detection step;

4 directing a first part of the acoustic signal from the first point towards a reflector at a fixed reference-distance from the first point;

5 detecting the return of an echo to the first point from the reflector of the first part of the acoustic signal;

6 recording as reference-time the time taken for the passage of the first part of the acoustic signal to the reflector and back to the first point;

7 detecting the arrival of an echo of the acoustic signal from the target surface at a second point at a fixed separation-distance from the first point and between the first point and the target surface;

8 recording as target-time the time taken for the arrival of the echo of the signal at the second point;

9 determining the distance between the second-point and the target to by multiplying the ratio of the reference-time to the target-time by the reference-distance and then subtracting one half of the separation-distance.

3 A method of measuring distance as claimed in Claim 1 or Claim 2 wherein the separation-distance is zero.

4 Apparatus for measuring the distance to a target surface characterised by:

1 a transmitter for propagating an acoustic signal along a path towards the target;

2 a platform located at a fixed position along the propagation path and partially intercepting the acoustic signal;

3 a first acoustic receiver positioned on the platform to detect the propagated acoustic signal;

4 a second acoustic receiver positioned on the platform to detect an echo of the propagated acoustic signal from the target;

5 means for the control of the transmitter;

6 timing means for determining a time of passage of the propagated signal to the first acoustic receiver and a time of arrival of an echo from

the target at the second acoustic receiver;

7 computation means for deriving the distance of the target relative to the apparatus from the determined times and the known positions of the receivers relative to the transmitter.

4 Apparatus for measuring the distance to a target surface comprising:

1 a transmitter for propagating an acoustic signal along a path towards the target, the transmitter being adapted of reflecting selected acoustic signals received from the path back along the path of propagation;

2 a platform located at a fixed position along the propagation path and partially intercepting the acoustic signal, the platform being shaped to reflect a portion of the propagated signal back towards the transmitter;

3 a first acoustic receiver positioned on the platform to detect the propagated acoustic signal and to detect a subsequent echo of that signal from the portion reflected along the path from the transmitter;

4 a second acoustic receiver positioned on the platform to detect an echo of the propagated acoustic signal from the target;

5 means for the controlling the transmitter;

6 timing means for determining a time of passage of the portion of the propagated signal reflected back to the transmitter and returned as a reference echo to the first acoustic receiver and the time of arrival of the echo at the second acoustic receiver from the target;

7 computation means for deriving the distance of the target relative to the apparatus from the determined times and the known positions of the receivers relative to the transmitter.

5 Apparatus as claimed in Claim 3 or Claim 4 wherein the first and second acoustic receivers are separated along the path length by a separation distance.

6 Apparatus as claimed in Claim 5 wherein the separation distance is zero.

7 Apparatus as hereinbefore described with reference to and as illustrated in Figure 1 or Figure 2 of the accompanying drawings

Patents Act 1977
Examiner's report to the Comptroller under Se on 17 (The Search Report)

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Relevant Technical fields

(i) UK Cl (Edition L) G1G (GRE)

(ii) Int Cl (Edition 5) G01S 15/00, 15/02, 15/06, 15/08, 15/10

Search Examiner
S J MORGAN

Databases (see over)
(i) UK Patent Office

(ii)

Date of Search
3 MARCH 1993

Documents considered relevant following a search in respect of claims 1-6

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
A	EP 0221785 A (KAWASAKI) - whole document	1, 4
A	EP 0037196 A (SKGNATIC) - whole document	1, 4

Category	Identity of document and relevant passages	Relevant to claim(s)

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